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(54) **FOLDABLE DISPLAY APPARATUS AND METHOD OF MANUFACTURING THE SAME**

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H01L 27/32 (2006.01)
H01L 51/00 (2006.01)

(52) **U.S. Cl.**

CPC ***H05K 1/028*** (2013.01); ***H01L 27/326*** (2013.01); ***H01L 51/0097*** (2013.01); *Y02E 10/549* (2013.01); *Y02P 70/521* (2015.11); *Y10T 29/49* (2015.01)

(58) **Field of Classification Search**

CPC H01L 27/326; H01L 51/0097; Y02E 10/549; Y02P 70/521; H05K 1/028; Y10T 29/49

USPC 349/158

See application file for complete search history.

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(57) **ABSTRACT**

A display apparatus includes a flexible substrate, first pixels, and second pixels. The flexible substrate includes: a first area at least partially bent about an axis; and at least one non-bent area. The first pixels are disposed in the first area. The second pixels are disposed in the at least one non-bent area. Respective widths of each first pixel in a first direction are smaller than respective widths of each second pixel in the first direction.

18 Claims, 3 Drawing Sheets

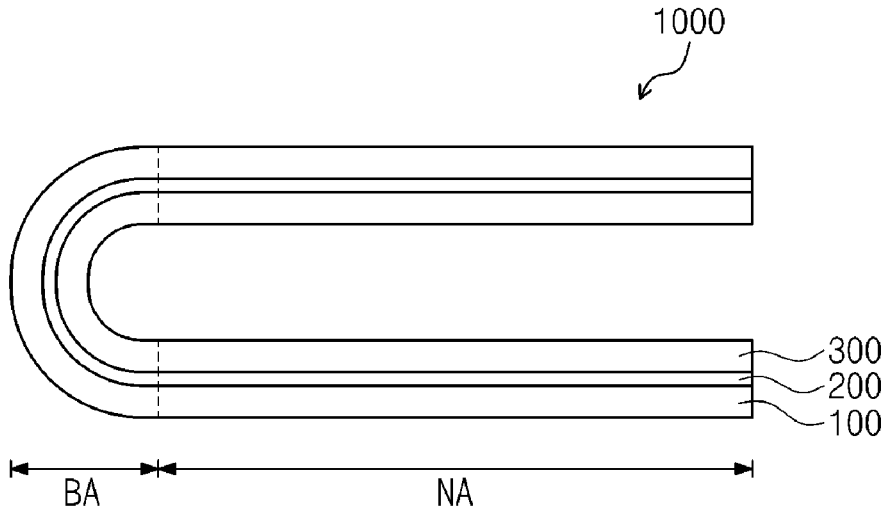


Fig. 1

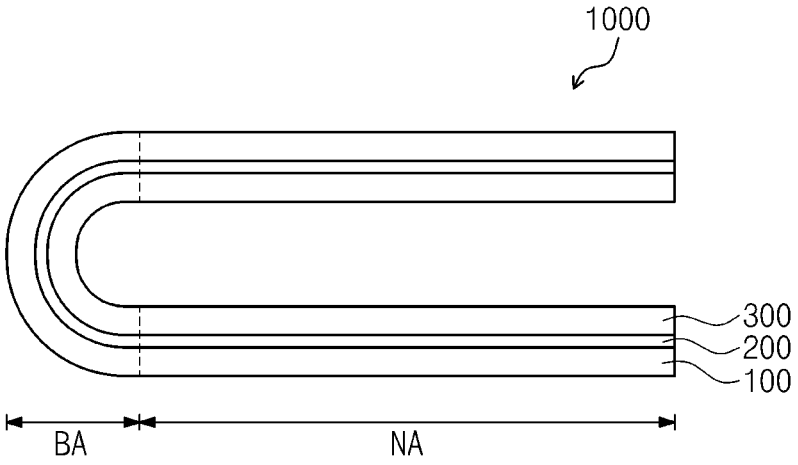


Fig. 2

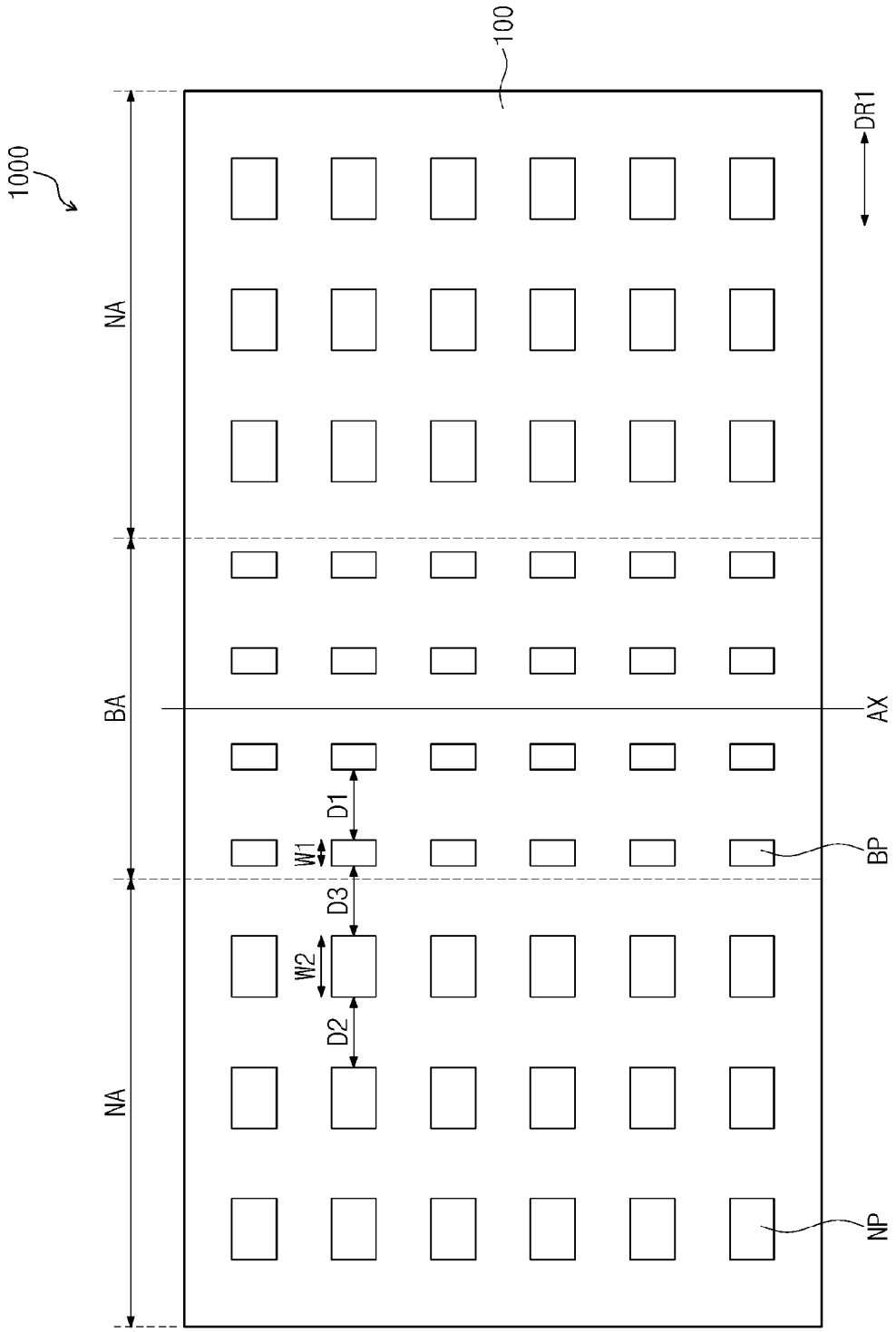
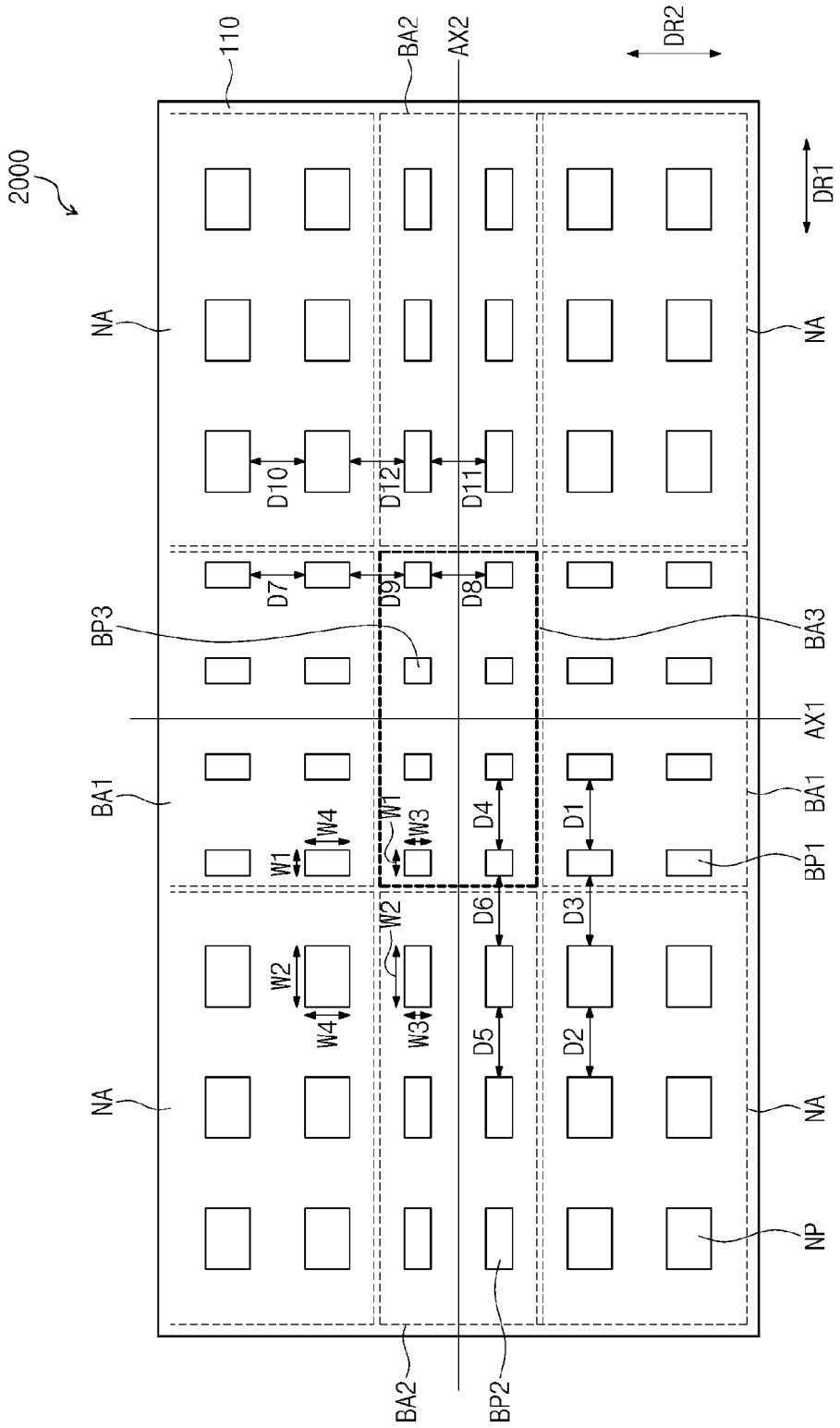


Fig. 3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110
BA2
AX2
DR2
DR1
NA
NA
D10
D12
D11
D7
D9
D8
BP3
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BA1
BA1
W1
W4
W1
W3
D4
D1
BP1
W2
W2
W4
W3
D6
D3
D5
D2
NA
NA
NP
BA2
BP2

FOLDABLE DISPLAY APPARATUS AND METHOD OF MANUFACTURING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from and the benefit of Korean Patent Application No. 10-2013-0087545, filed on Jul. 24, 2013, which is incorporated by reference for all purposes as if set forth herein.

BACKGROUND

1. Field

Exemplary embodiments relate to a foldable display apparatus and a method of manufacturing the same, and, more particularly, to a foldable display apparatus having improved display quality and a method of manufacturing the same.

2. Discussion

Conventional foldable displays are typically formed by depositing, for example, organic light emitting materials on a flexible display substrate. In this manner, a foldable display apparatus may be folded, bent, rolled, or otherwise deformed (hereinafter collectively referred to as "bent") to a designed limit radius of curvature. As such, a foldable display apparatus may include a bent (or flexed) area including at least one bend and a non-bent area that does not include at least one bend. Pixels may be formed in each of the bent and non-bent areas. It is noted that each of the pixels may include a thin film transistor and electrodes, each of which are vulnerable to defects related to bending forces. As such, when a flexible display substrate is bent, cracks may occur in one or more components of the pixels formed in the bent area. To this end, when distances between the pixels and the bending axis in a perpendicular direction are different, at least one line in a direction parallel to the bending axis may be observed.

The above information disclosed in this Background section is only for enhancement of understanding of the background of the inventive concept, and, therefore, it may contain information that does not form the prior art that is already known in this country to a person of ordinary skill in the art.

SUMMARY

Exemplary embodiments provide a foldable display apparatus configured to prevent (or otherwise reduce) cracks in pixels formed in a bent area of the foldable display, as well as prevent (or otherwise reduce) the occurrence of visible lines in a direction substantially parallel to a bending axis of the bent area. In this manner, display quality may be improved.

Exemplary embodiments provide a method of manufacturing the foldable display apparatus.

Additional aspects will be set forth in the detailed description which follows and, in part, will be apparent from the disclosure, or may be learned by practice of the inventive concept.

According to exemplary embodiments, a display apparatus includes a flexible substrate, first pixels, and second pixels. The flexible substrate includes: a first area at least partially bent about an axis; and at least one non-bent area. The first pixels are disposed in the first area. The second pixels are disposed in the at least one non-bent area. Respective widths of each first pixel in a first direction are smaller than respective widths of each second pixel in the first direction.

According to exemplary embodiments, a display apparatus includes a flexible substrate, first pixels, second pixels, third pixels, and fourth pixels. The flexible substrate includes: a first area at least partially bent about a first axis; a second area at least partially bent about a second axis different from the first axis, a third area at least partially bent about each of the first axis and the second axis; and at least one non-bent area. The first pixels are disposed in the first area. The second pixels are disposed in the second area. The third pixels are disposed in the third area. The fourth pixels are disposed in the at least one non-bent area. Respective widths of each first pixel and each third pixel in the first direction are smaller than respective widths of each fourth pixel and each second pixel in a first direction. Respective widths of each second pixel and each third pixel in a second direction different from the first direction are smaller than respective widths of each fourth pixel and each first pixel in the second direction.

According to exemplary embodiments, a method includes: forming first pixels on a first portion of a flexible substrate; forming second pixels on a second portion of the flexible substrate; and bending the first portion of the flexible substrate at least partially about an axis. Respective widths of each first pixel in a first direction are smaller than respective widths of each second pixel in the first direction.

According to exemplary embodiments, a method includes: forming first pixels on a first portion of a flexible substrate; forming second pixels on a second portion of the flexible substrate; forming third pixels on a third portion of the flexible substrate; forming fourth pixels on a fourth portion of the flexible substrate; bending the first portion at least partially about a first axis; and bending the second portion at least partially about a second axis different from the first axis. Bending the first portion and bending the second portion bends the third portion at least partially about each of the first axis and the second axis. Respective widths of each first pixel and each third pixel in a first direction are smaller than respective widths of each fourth pixel and each second pixel in the first direction. Respective widths of each second pixel and each third pixel in a second direction different from the first direction are smaller than respective widths of each fourth pixel and each first pixel in the second direction.

The foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are included to provide a further understanding of the inventive concept, and are incorporated in and constitute a part of this specification, illustrate exemplary embodiments of the inventive concept, and, together with the description, serve to explain principles of the inventive concept.

FIG. **1** is a sectional view of a foldable display apparatus, according to exemplary embodiments.

FIG. **2** is a plan view of the foldable display apparatus of FIG. **1**, according to exemplary embodiments.

FIG. **3** is a plan view of a foldable display apparatus, according to exemplary embodiments.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of various exemplary embodiments. It is apparent, however, that various exemplary embodiments may be practiced without these specific details or with one or more equivalent arrangements. In other instances, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring various exemplary embodiments.

In the accompanying figures, the size and relative sizes of layers, films, panels, regions, etc., may be exaggerated for clarity and descriptive purposes. Also, like reference numerals denote like elements.

When an element or layer is referred to as being "on," "connected to," or "coupled to" another element or layer, it may be directly on, connected to, or coupled to the other element or layer or intervening elements or layers may be present. When, however, an element or layer is referred to as being "directly on," "directly connected to," or "directly coupled to" another element or layer, there are no intervening elements or layers present. For the purposes of this disclosure, "at least one of X, Y, and Z" and "at least one selected from the group consisting of X, Y, and Z" may be construed as X only, Y only, Z only, or any combination of two or more of X, Y, and Z, such as, for instance, XYZ, XYY, YZ, and ZZ. Like numbers refer to like elements throughout. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

Although the terms first, second, etc. may be used herein to describe various elements, components, regions, layers, and/or sections, these elements, components, regions, layers, and/or sections should not be limited by these terms. These terms are used to distinguish one element, component, region, layer, and/or section from another element, component, region, layer, and/or section. Thus, a first element, component, region, layer, and/or section discussed below could be termed a second element, component, region, layer, and/or section without departing from the teachings of the present disclosure.

Spatially relative terms, such as "beneath," "below," "lower," "above," "upper," and the like, may be used herein for descriptive purposes, and, thereby, to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the drawings. Spatially relative terms are intended to encompass different orientations of an apparatus in use, operation, and/or manufacture in addition to the orientation depicted in the drawings. For example, if the apparatus in the drawings is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the exemplary term "below" can encompass both an orientation of above and below. Furthermore, the apparatus may be otherwise oriented (e.g., rotated 90 degrees or at other orientations), and, as such, the spatially relative descriptors used herein interpreted accordingly.

The terminology used herein is for the purpose of describing particular embodiments and is not intended to be limiting. As used herein, the singular forms, "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. Moreover, the terms "comprises," comprising," "includes," and/or "including," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, components, and/or groups thereof, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

Various exemplary embodiments are described herein with reference to sectional illustrations that are schematic illustrations of idealized exemplary embodiments and/or intermediate structures. As such, variations from the shapes of the illustrations as a result, for example, of manufacturing techniques and/or tolerances, are to be expected. Thus, exemplary embodiments disclosed herein should not be construed as limited to the particular illustrated shapes of regions, but are to include deviations in shapes that result from, for instance, manufacturing. For example, an implanted region illustrated as a rectangle will, typically, have rounded or curved features and/or a gradient of implant concentration at its edges rather than a binary change from implanted to non-implanted region. Likewise, a buried region formed by implantation may result in some implantation in the region between the buried region and the surface through which the implantation takes place. Thus, the regions illustrated in the drawings are schematic in nature and their shapes are not intended to illustrate the actual shape of a region of a device and are not intended to be limiting.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure is a part. Terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense, unless expressly so defined herein.

FIG. **1** is a sectional view of a foldable display apparatus, according to exemplary embodiments.

Referring to FIG. **1**, a foldable display apparatus **1000** may be a flexible display apparatus, such as a flexible organic light emitting display apparatus. For descriptive and illustrative convenience, exemplary embodiments are described in association with an organic light emitting display apparatus implementation of the foldable display apparatus **1000**. It is contemplated, however, that any other suitable form of foldable, bendable, flexible, or otherwise deformable display apparatus may be utilized.

According to exemplary embodiments, the foldable display apparatus **1000** includes a display substrate **100**, a pixel layer **200**, and an encapsulation substrate **300**. Although specific reference will be made to this particular implementation, it is also contemplated that the foldable display apparatus **1000** may embody many forms and include multiple and/or alternative components and configurations.

The display substrate **100** may be a flexible insulating substrate form of any suitable material. The display substrate **100** may include a bending area BA where bending occurs, as well as at least one non-bending area NA where bending may not occur.

The pixel layer **200** may be disposed on the display substrate **100**. The pixel layer **200** may include pixels to display an image. The pixels may be separated from one another. In this manner, an image may not be displayed in areas between adjacent pixels. Although not shown in the drawings, each of the pixels may include a thin film transistor (TFT), an anode, a hole injection layer, a hole transport layer, an organic emission layer, an electron transport layer, an electron injection layer, and a cathode.

The encapsulation substrate **300** may be disposed on the pixel layer **200** to face the display substrate **100**. In this manner, the pixel layer **200** may be disposed between the display substrate **100** and the encapsulation substrate **300**. In exemplary embodiments, the encapsulation substrate **300** may encapsulate and protect the pixel layer **200** from an external environment, e.g., dust, debris, gasses, impacts, etc. It is also noted that the encapsulation substrate **300** may be a flexible insulating substrate made of any suitable material.

Although not shown, the foldable display apparatus **1000** may further include at least one driving unit to provide a driving signal to the pixels. The driving unit may be mounted on a printed circuit board. The foldable display apparatus **1000** may also include at least one controller and one or more memories to facilitate the display of images.

FIG. **2** is a plan view of the foldable display apparatus of FIG. **1**, according to exemplary embodiments.

Referring to FIG. **2**, the foldable display apparatus **1000** may be at least partially bent about a bending axis AX in, for example, a first direction DR**1** perpendicular (or substantially perpendicular) to a direction in which the bending axis AX extends.

According to exemplary embodiments, the pixels may be configured to display at least one color, such as, for instance, red, green, blue, white, or any other suitable color. For example, the pixels may be arranged in RGB stripes of red, green, and blue pixels. To this end, each of the pixels may include at least two sub-pixels configured to display different colors from one another. Moreover, the pixels may include first pixels BP disposed in association with the bending area BA and second pixels NP disposed in association with at least one of the non-bending areas NA of the display substrate **100**. Hereinafter, the first pixels BP may be referred to as bending pixels BP and the second pixels may be referred to as non-bending pixels NP; however, these monikers are not to be construed as connoting a bent/non-bent state of the pixels.

In exemplary embodiments, a width of each of the bending pixels BP in the first direction DR**1** may be a first width W**1**, and a width of each of the non-bending pixels NP in the first direction DR**1** may be a second width W**2**. The first width W**1** may be smaller than the second width W**2**. For instance, a relation between the first width W**1** and the second width W**2** may satisfy Equation 1.

$$0.1\times W2\leq W1\leq 0.9\times W2 \qquad \text{Equation (1)}$$

A radius curvature of the bending area BA may be proportional to the first width W**1**. For example, as the radius curvature of the bending area BA becomes smaller, the first width W**1** may become smaller.

It is noted that a higher probability of defects may otherwise occur in the bending pixels BP than the non-bending pixels NP. For example, as the bending area BA bends, cracks may occur in one or more of the TFTs, anodes, and/or cathodes of the bending pixels BP. In exemplary embodiments, however, since the first width W**1** may be smaller than the second width W**2**, the bending pixels BP may be less stressed than the non-bending pixels NP or at least stressed less than if the widths of the bending pixels BP were the same as or greater than the widths of the non-bending pixels NP. As such, exemplary embodiments reduce the probability of defects occurring in the bending pixels BP.

According to exemplary embodiments, distances between adjacent pixels in the first direction DR**1** may be identical (or substantially identical) to one another. That is, a distance between the bending pixels BP in the first direction DR**1** may be a first distance D**1**, a distance between the non-bending pixels NP in the first direction DR**1** may be a second distance D**2**, and a distance between the bending pixels BP and the non-bending pixels NP that are adjacent to one another in the first direction DR**1** may be a third distance D**3**. In this manner, the first distance D**1**, the second distance D**2**, and the third distance D**3** may be identical (or substantially identical) to one another.

When, however, the first distance D**1**, the second distance D**2**, and the third distance D**3** are not identical (or substantially identical) to one another, an observable line may present itself and display quality may be deteriorated. That is, when a different amount of non-display area is disposed between adjacent columns of pixels, the aggregated effect may cause at least one observable line of non-display area to be more readily noticeable to an observer. For example, when the first distance D**1** and the second distance D**2** are identical to each other and the third distance D**3** is different from the first distance D**1** and the second distance D**2**, at least one observable line may present itself between adjacent bending pixels BP and non-bending pixels NP in the first direction DR**1**. The observable line(s) may extend in a direction parallel (or substantially parallel) to the bending axis AX. In exemplary embodiments, however, since the first distance D**1**, the second distance D**2**, and the third distance D**3** may be identical (or substantially identical) to one another, the aforementioned observable line(s) may be prevented and display quality may be improved.

According to exemplary embodiments, a method of manufacturing the foldable display apparatus **1000** of FIGS. **1** and **2** may include forming a plurality of pixels on a display substrate **100** including a bending area BA in which at least one bend may occur in a first direction DR**1** at least partially about a bending axis AX and a non-bending area NA, which may not include at least one bend. At least some of the pixels may be disposed in association with the bending area BA, and, thereby, considered bending pixels BP. Other ones of the pixels may be disposed in association with the non-bending area NA, and, thereby, considered non-bending pixels NP. The relative sizes and spatial positions of the bending pixels BP and the non-bending pixels NP may be consistent with exemplary embodiments described in association with FIGS. **1** and **2**, and, as such, a duplicative description will be omitted to ovoid obscuring exemplary embodiments described herein.

FIG. **3** is a plan view of a foldable display apparatus, according to exemplary embodiments. It is noted that the foldable display apparatus **2000** of FIG. **3** may be substantially similar to the foldable display apparatus **1000** of FIGS. **1** and **2**. As such, to avoid obscuring exemplary embodiments described herein, differences between the foldable display apparatus **2000** and the foldable display apparatus **1000** will be described below.

As seen in FIG. **3**, the foldable display apparatus **2000** may be bent (or otherwise deformed) in a first direction DR**1** at least partially about a first bending axis AX**1** perpendicular (or substantially perpendicular) to the first direction DR**1**. The foldable display apparatus **2000** may also be bent in a second direction DR**2** at least partially about a second bending axis AX**2**, which may be perpendicular (or substantially perpendicular) to the second direction DR**2**. In this manner, the first bending axis AX**1** and the second bending axis AX**2** may cross one another, as may the first direction DR**1** and the second direction DR**2**. To this end, the first bending axis AX**1** may extend (or substantially extend) in the second direction DR**2**, whereas the second bending axis AX**2** may extend (or substantially extend) in the first direction DR**1**.

According to exemplary embodiments, the foldable display apparatus **2000** may include a display substrate **110**. The display substrate **110** may include first bending areas BA**1**, second bending areas BA**2**, a third bending area BA**3**, and non-bending areas NA. It is noted that the first bending areas BA**1** may be bent in the first direction DR**1** at least partially about the first bending axis AX**1**, but may not be bent in the second direction DR**2**. To this end, the second bending areas BA**2** may be bent in the second direction DR**2** at least partially about the second bending axis AX**2**, but may not be bent in the first direction DR**1**. The third bending area BA**3** may be bent in the first direction DR**1** at least partially about the first bending axis AX**1** and bent in the second direction DR**2** at least partially about the second bending axis AX**2**. Further, the non-bending areas NA may not include a bend in either of the first direction DR**1** or the second direction DR**2**.

In exemplary embodiments, the foldable display apparatus **2000** includes a plurality of pixels disposed on the display substrate **110**. The plurality of pixels includes first bending pixels BP**1** disposed in the first bending areas BA**1**, second bending pixels BP**2** disposed in the second bending areas BA**2**, third bending pixels BP**3** disposed in the third bending area BA**3**, and non-bending pixels NP disposed in the non-bending areas NA. Widths of the respective first bending pixels BP**1** and the respective third bending pixels BP**3** in the first direction DR**1** may be first widths W**1**, and widths of the respective second bending pixels BP**2** and the respective non-bending pixels NP in the first direction DR**1** may be second widths W**2**. In this manner, the first width W**1** may be smaller than the second width W**2**. A relation between the first width W**1** and the second width W**2** may satisfy Equation 1 described above.

A radius of curvature of the first bending areas BA**1** at least partially about the first bending axis AX**1** may be proportional to the first width W**1**. For example, as the radius of curvature of the first bending areas BA**1** becomes smaller, the first width W**1** may become smaller.

According to exemplary embodiments, widths of the respective second bending pixels BP**2** and the respective third bending pixels BP**3** in the second direction DR**2** may be third widths W**3**, and widths of the respective first bending pixels BP**1** and the respective non-bending pixels NP in the second direction DR**2** may be fourth widths W**4**. In this manner, the third width W**3** may be smaller than the fourth width W**4**. That is, a relation between the third width W**3** and the fourth width W**4** may satisfy Equation 2.

$$0.1\times W4\leq W3\leq 0.9\times W4 \qquad \text{Equation (2)}$$

A radius of curvature of the second bending areas BA**2** at least partially about the second bending axis may be proportional to the third width W**3**. For example, as the radius of curvature of the second bending areas BA**2** becomes smaller, the third width W**3** may become smaller.

In exemplary embodiments, distances between adjacent pixels in the first direction DR**1** may be identical to one another. Distances between adjacent pixels in the second direction DR**2** may be identical to one another.

A distance between the first bending pixels BP**1** in the first direction DR**1** may be a first distance D**1**, a distance between the non-bending pixels NP in the first direction DR**1** may be a second distance D**2**, a distance between the first bending pixels BP**1** and the non-bending pixels NP adjacent to one another in the first direction D**1** may be a third distance D**3**, a distance between the third bending pixels BP**3** in the first direction DR**1** may be a fourth distance D**4**, a distance between the second bending pixels BP**2** in the first direction DR**1** may be a fifth distance D**5**, and a distance between the second bending pixels BP**2** and the third bending pixels BP**3** adjacent to one another in the first direction DR**1** may be a sixth distance D**6**. To this end, the first distance D**1**, the second distance D**2**, the third distance D**3**, the fourth distance D**4**, the fifth distance D**5**, and the sixth distance D**6** may be identical to one another.

A distance between the first bending pixels BP**1** in the second direction DR**2** may be a seventh distance D**7**, a distance between the third bending pixels BP**3** in the second direction DR**2** may be an eighth distance D**8**, a distance between the first bending pixels BP**1** and the third bending pixels BP**3** adjacent to one another in the second direction DR**2** may be a ninth distance D**9**, a distance between the non-bending pixels NP in the second direction DR**2** may be a tenth distance D**10**, a distance between the second bending pixels BP**2** in the second direction DR**2** may be an eleventh distance D**11**, and a distance between the non-bending pixels NP and the second bending pixels BP**2** adjacent to one another in the second direction DR**2** may be a twelfth distance D**12**. To this end, the seventh distance D**7**, the eighth distance D**8**, the ninth distance D**9**, the tenth distance D**10**, the eleventh distance D**11**, and the twelfth distance D**12** may be identical to one another.

According to exemplary embodiments, the configuration of the foldable display apparatus **2000** of FIG. **3** may not only reduce a probability of defects occurring in the first bending pixels BP**1** and the third bending pixels BP**3**, but may also reduce a probability of defects occurring in the second bending pixels BP**2** and the third bending pixels BP**3**. To this end, exemplary embodiments not only prevent observable lines extending in the second direction DR**2** from being noticed due to the first distance D**1** to the sixth distance D**6** being identical to one another, but also prevent observable lines extending in the first direction DR**1** from being noticed due to the seventh distance D**7** to the twelfth distance D**12** being identical to one another. In this manner, display quality may be improved.

According to exemplary embodiments, a method of manufacturing the foldable display apparatus **2000** of FIG. **3** may include forming a plurality of pixels on a display substrate **110** including first bending areas BA**1** in which at least one bend occurs in a first direction DR**1** at least partially about a first bending axis AX**1**, second bending areas BA**2** in which at least one bend occurs in a second direction DR**2** at least partially about a second bending axis AX**2** (where the second direction DR**2** crosses the first direction DR**1**), a third bending area BA**3** in which at least one bend occurs in each of the first direction DR**1** and the second direction DR**2** at least partially about the first bending axis AX**1** and the second bending axis AX**2**, respectively, and non-bending areas NA, which may not include at least one bend. Each of the first bending areas BA**1**, the second bending areas BA**2**, the third bending area BA**3**, and the non-bending areas NA may respectively include corresponding ones of the pixels. That is, the first bending areas BA**1** may include first bending pixels BP**1**, the second bending areas BA**2** may include second bending pixels BP**2**, the third bending area BA**3** may include third bending pixels BP**3**, and the non-bending areas NA may include non-bending pixels NP. The relative sizes and spatial positions of the first bending pixels BP**1**, the second bending pixels BP**2**, the third bending pixels BP**3**, and the non-bending pixels NP may be consistent with exemplary embodiments described in association with FIGS. **1** to **3**, and, as such, a duplicative description will be omitted to avoid obscuring exemplary embodiments described herein.

According to exemplary embodiments, cracks may be prevented (or otherwise reduced) from occurring in pixels formed in one or more bent areas of a foldable display apparatus. To this end, exemplary embodiments may also prevent the occurrence of one or more lines from being formed in directions substantially parallel to bending axes of the bent areas that may otherwise be observed. In this manner, exemplary embodiments may improve display quality of foldable display apparatuses.

Although certain exemplary embodiments and implementations have been described herein, other embodiments and modifications will be apparent from this description. Accordingly, the inventive concept is not limited to such embodiments, but rather to the broader scope of the presented claims and various obvious modifications and equivalent arrangements.

What is claimed is:

1. A display apparatus, comprising:

a flexible substrate comprising:

a first area at least partially bent about an axis; and

at least one non-bent area;

first pixels disposed in the first area; and

second pixels disposed in the at least one non-bent area,

wherein the first pixels have the same size as one another,

wherein the second pixels have the same size as one another,

wherein respective widths of each first pixel in a first direction are smaller than respective widths of each second pixel in the first direction, and

wherein a distance between first pixels adjacent to one another in the first direction, a distance between second pixels adjacent to one another in the first direction, and a distance between first pixels and second pixels adjacent to one another in the first direction are the same as one another.

2. The display apparatus of claim **1**, wherein:

the respective width of each first pixel in the first direction is W**1**;

the respective width of each second pixel in the first direction is W**2**; and

$$0.1\times W2\leq W1\leq 0.9\times W2.$$

3. The display apparatus of claim **1**, wherein the first direction is substantially perpendicular to the axis.

4. A display apparatus, comprising:

a flexible substrate comprising:

a first area at least partially bent about a first axis,

a second area at least partially bent about a second axis different from the first axis,

a third area at least partially bent about each of the first axis and the second axis, and

at least one non-bent area;

first pixels disposed in the first area;

second pixels disposed in the second area;

third pixels disposed in the third area; and

fourth pixels disposed in the at least one non-bent area,

wherein the first pixels have the same size as one another,

wherein the second pixels have the same size as one another,

wherein the third pixels have the same size as one another,

wherein the fourth pixels have the same size as one another,

wherein respective widths of each first pixel and each third pixel in a first direction are smaller than respective widths of each fourth pixel and each second pixel in the first direction, and

wherein respective widths of each second pixel and each third pixel in a second direction different from the first direction are smaller than respective widths of each fourth pixel and each first pixel in the second direction.

5. The display apparatus of claim **4**, wherein a distance between first pixels adjacent to one another in the first direction, a distance between fourth pixels adjacent to one another in the first direction, a distance between first pixels and fourth pixels adjacent to one another in the first direction, a distance between third pixels adjacent to one another in the first direction, a distance between second pixels adjacent to one another in the first direction, and a distance between second pixels and third pixels adjacent to one another in the first direction are substantially the same.

6. The display apparatus of claim **4**, wherein a distance between first pixels adjacent to one another in the second direction, a distance between third pixels adjacent to one another in the second direction, a distance between first pixels and third pixels adjacent to one another in the second direction, a distance between fourth pixels adjacent to one another in the second direction, a distance between second pixels adjacent to one another in the second direction, and a distance between fourth pixels and second pixels adjacent to one another in the second direction are substantially the same.

7. The display apparatus of claim **4**, wherein:

the respective widths of each first pixel and each third pixel in the first direction are W**1**;

the respective widths of each second pixel and each fourth pixel in the first direction are W**2**; and

$$0.1\times W2\leq W1\leq 0.9\times W2.$$

8. The display apparatus of claim **4**, wherein:

the respective widths of each second pixel and each third pixel in the second direction are W**3**;

the respective widths of each first pixel and each fourth pixel in the second direction are W**4**; and

$$0.1\times W4\leq W3\leq 0.9\times W4.$$

9. The display apparatus of claim **4**, wherein:

the first direction is substantially perpendicular to the first axis;

the second direction is substantially perpendicular to the second axis;

the first direction and the second axis are substantially parallel; and

the second direction and the first axis are substantially parallel.

10. A method, comprising:

forming first pixels on a first portion of a flexible substrate;

forming second pixels on a second portion of the flexible substrate; and

bending the first portion of the flexible substrate at least partially about an axis,

wherein the first pixels have the same size as one another,

wherein the second pixels have the same size as one another,

wherein respective widths of each first pixel in a first direction are smaller than respective widths of each second pixel in the first direction, and

wherein a distance between first pixels adjacent to one another in the first direction, a distance between second pixels adjacent to one another in the first direction, and a distance between first pixels and second pixels adjacent to one another in the first direction are substantially the same.

11. The method of claim **10**, wherein:

the respective width of each first pixel in the first direction is W**1**;

the respective width of each second pixel in the first direction is W**2**; and

$$0.1\times W2\leq W1\leq 0.9\times W2.$$

12. The method of claim **10**, wherein the first direction is substantially perpendicular to the axis.

13. A method, comprising:

forming first pixels on a first portion of a flexible substrate;

forming second pixels on a second portion of the flexible substrate;

forming third pixels on a third portion of the flexible substrate;

forming fourth pixels on a fourth portion of the flexible substrate;

bending the first portion at least partially about a first axis; and

bending the second portion at least partially about a second axis different from the first axis,

wherein bending the first portion and bending the second portion bends the third portion at least partially about each of the first axis and the second axis,

wherein the first pixels have the same size as one another,

wherein the second pixels have the same size as one another,

wherein the third pixels have the same size as one another,

wherein the fourth pixels have the same size as one another,

wherein respective widths of each first pixel and each third pixel in a first direction are smaller than respective widths of each fourth pixel and each second pixel in the first direction, and

wherein respective widths of each second pixel and each third pixel in a second direction different from the first direction are smaller than respective widths of each fourth pixel and each first pixel in the second direction.

14. The method of claim **13**, wherein a distance between first pixels adjacent to one another in the first direction, a distance between fourth pixels adjacent to one another in the first direction, a distance between first pixels and fourth pixels adjacent to one another in the first direction, a distance between third pixels adjacent to one another in the first direction, a distance between second pixels adjacent to one another in the first direction, and a distance between second pixels and third pixels adjacent to one another in the first direction are substantially the same.

15. The method of claim **13**, wherein a distance between first pixels adjacent to one another in the second direction, a distance between third pixels adjacent to one another in the second direction, a distance between first pixels and third pixels adjacent to one another in the second direction, a distance between fourth pixels adjacent to one another in the second direction, a distance between second pixels adjacent to one another in the second direction, and a distance between fourth pixels and second pixels adjacent to one another in the second direction are substantially the same.

16. The method of claim **13**, wherein:

the respective widths of each first pixel and each third pixel in the first direction are W**1**;

the respective widths of each second pixel and each fourth pixel in the first direction are W**2**; and

$$0.1\times W2\leq W1\leq 0.9\times W2.$$

17. The method of claim **13**, wherein:

the respective widths of each second pixel and each third pixel in the second direction are W**3**;

the respective widths of each first pixel and each fourth pixel in the second direction are W**4**; and

$$0.1\times W4\leq W3\leq 0.9\times W4.$$

18. The method of claim **13**, wherein:

the first direction is substantially perpendicular to the first axis;

the second direction is substantially perpendicular to the second axis;

the first direction and the second axis are substantially parallel; and

the second direction and the first axis are substantially parallel.

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